Comparison of Different Transmit Diversity Space-Time Code Algorithms

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Abstract. *Recently, it has been proven that employing more than one transmit antenna increases channel throughput, and different strategies have been developed in order to achieve transmit diversity advantage. Space-time codes combine coding gain with diversity gain and preserve orthogonality between antennas, whereas BLAST (Bell Labs Layered Space-Time Architecture) technology transmits different independent bitstreams from each transmit antenna and employs an interference nulling-interference cancelling decoding algorithm. In this paper we present a comparison of these transmit diversity techniques in terms of Bit Error Rate (BER) for a Multi-Input Multi-Output (MIMO) channel, specifically we compare space-time block codes (STBC), space-time trellis codes (STTC) and BLAST architecture).*

1 Introduction

On one hand, the convergence of telecommunications, computers and multimedia technologies has drawn a new scenario and requirements that should be taken into account when designing 3th Generation Mobile Systems standards, such as UMTS. It is expected that in the year 2015 the penetration tax for multimedia services will be round 60% with an increasing demand of both data rate and number of active users. Currently most GSM operators can only provide 9.6 Kbps using circuit switched technology that is clearly not adequate for data services. Implementation of GPRS and EDGE will provide 92 Kbps and 384 Kbps per user, respectively. Finally, UMTS will be able to offer data rate services at 2 Mbps. On the other hand, wireless channels suffer from shadowing and multipath propagation that produce high attenuation effects on the transmitted signal resulting in burst errors, which can be partially resolved if some kind of diversity can be exploited. However, time or frequency diversity will not always be available, hence we might not assume to be able to exploit them in all scenarios. Employing more than one antenna at the transmitter site provides an additional diversity advantage since multiple parallel (possibly independent) channels can be combined to combat the fading effects.

Using several transmit antennas increases the capacity of wireless channels [1], hence the goal of those transmit strategies is to combine efficiently all possible resources (transmit diversity, coding gain, receive diversity,...) to increase the channel throughput, either via concatenation of different blocks or jointly designed space-time codes.

There is an increasing interest in working out new schemes capable of decreasing the BER without bandwidth expansion and space-time codes satisfy these properties. The Alamouti code has already been included in the standardisation process of UMTS in conjunction with conventional channel codes (convolutional and turbo codes) for the base-station to mobile unit link (downlink).

However, all these transmit diversity strategies can be applied either in the uplink or the downlink. At frequencies close to 2 GHz a separation of 5-8 cm between antennas is enough to ensure low correlation coefficients. For 3th Generation Mobile Systems (i.e. UMTS) it is possible to employ more than one antenna in the mobile unit since only 5-8 cm are required to obtain two, low correlated, channel paths for each antenna, and mobile terminals will be, theoretically, larger than 5 cm because they must incorporate bigger displays than those of GSM to hold multimedia services.

The METRA project, carried out under the IST (Information Society Technologies) Programme by Universitat Politècnica de Catalunya, which acts as project coordinator, the Center for PersonKommunikation of Aalborg University, Nokia Networks, Nokia Mobile Phones and Vodafone Ltd., concerns the study of Multi-element Transmit and Receive Antennas focused on UMTS. Especially, the METRA project analyses the improvement that can be obtained employing more than one antenna in the mobile for both transmit and receive links. This paper reflects the preliminary results obtained within the METRA project related to space-time coding [2].
The scope of this paper is to compare different transmit strategies for MIMO channels from a BER point of view and, in some cases, concatenate space-time codes with conventional convolutional codes or turbo codes. Those strategies considered herein are STBC, STTC, and BLAST. STBC [1] are a generalisation of the Alamouti code when more than two transmit antennas are used. At the same time Tarohk *et.al* also presented a space-time code that achieves full diversity (under some design restrictions) based on a trellis structure (STTC), which also provide non-negligible coding gain [4]. BLAST technology, which has been developed by Foschini *et. al* [[5]-[7]], transmits different independent bitstreams from each transmit antenna that have previously been encoded separately.
This paper is organised as follows. Section 2 describes the channel model, section 3 briefly presents all space-time algorithms simulated in this paper. Simulation results are discussed and analysed in section 4 and, finally, some conclusions are drawn in section 5.

2 System Model

We consider a system employing n_T transmit antennas and n_R receive antennas. Although the purpose of this paper is to analyse the performance of different space-time coding algorithms regardless of the modulation or number of antennas at both transmit and receive sites, a comparison with respect to the currently standardised STBC for the UMTS mobile system is convenient, therefore simulations are focused on two transmit antennas ($n_T=2$) and QPSK modulation.
Figure 1 shows the transmit scheme of the system considered in this paper. Information bits b_i are first encoded by an outer channel code, which can be a convolutional code or a turbo code as specified by 3GPP. The packet length to be encoded (N) depends on the information bit rate and TTI (Transmission Time Interval) but block segmentation should be performed if it is larger than the maximum admissible coding length, i.e. N=504 and N=5114 for convolutional codes and turbo codes, respectively. The frame for the UMTS 3[th] generation mobile system is divided into 15 timeslots, each one containing 2560 chips at a chip rate of 3.84 Mchip/s, hence each frame is transmitted in 10ms. The TTI takes values of 10, 20, 40 or 80ms depending on the service constraints.

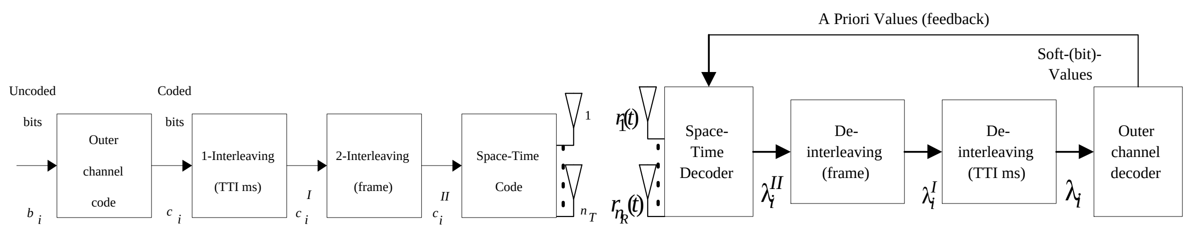

Figure 1: Block diagram of the transmitter and receiver

Coded bits c_i are fed to a first block interleaver which interleaves across different frames if TTI is larger than 10ms. Radio frame segmentation is performed before coded bits are interleaved (only within a frame) by a second block interleaver. Both interleaver patterns are specified in [8][9]. Finally, the space-time encoder outputs $d_i(t)$ $i=1..n_T$ symbol constellation points at each time slot t, which are transmitted simultaneously from each antenna i, $i=1..n_T$.
The signal constellation is scaled such that the total transmitted energy in normalised to unity. The energy is assumed to be equally distributed along all transmit antennas, hence the average energy out of each antenna is $1/n_T$. We consider a system employing $n_T=2$ transmit antennas and $n_R=2$ receive antennas. We restrict ourselves to $n_T=2$ since only two transmit antennas are being considered by the

3GPP standardisation group, and to a QPSK constellation. The received signal is a noisy filtered superposition of the transmitted signals,

$$r_j(t) = \sum_{i=1}^{n_T} h_{i,j}(t) d_i(t) + n_j(t)$$

where $r_j(t)$ $j=1..n_R$ denotes the received signal at time t at receive antenna j, $j=1..n_R$, and $n_j(t)$ represents an additive white Gaussian noise modelled as independent samples of a zero mean complex Gaussian random variable with variance $N_0/2$ per dimension. The parameters $h_{i,j}(t)$ denote the fading coefficient from transmit antenna i to receive antenna j at time t. Since the angular spread seen at the mobile is in general relatively large due to local scattering we assume that path gains between antennas at the mobile are independent. However this assumption is not applicable at the base station, where antennas are correlated owing to a small angular spread.

Figure 1 also shows the receive path of the system being considered. The space-time decoder computes the soft-(bit)-values (Log-Likelihood) of the transmitted bits from the received signal $r_j(t)$, $j=1...n_R$ and channel estimates $\bar{h}$,. In this paper we consider ideal channel estimation, that is, $\bar{h} = h$. After de-interleaving, the estimated soft-values are fed to the outer channel decoder.

As mentioned above, we can consider this system as the concatenation of an inner code with an outer code, hence it is an open question whether an iterative procedure that feeds back the output of the outer code to the inner code will improve the overall system performance, as it happens with turbo decoding. This feedback information has to be interleaved by the same interleaving patters that where present in the transmitter site.

3 Space-Time Algorithms

3.1 Space-Time Block Codes

A general STBC [1] maps every k input symbols into a $p \cdot n_T$ coded matrix, the columns representing those symbols transmitted from each transmit antenna during p different time slots. The rate of the code is defined as $r = k/p$. STBC are a generalisation to more than two transmit antennas of the Alamouti code, whose code matrix is:

$$G_A = \begin{pmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{pmatrix}$$

where * stands for complex conjugate. Note that this code does not require any bandwidth expansion since $r = 1$.

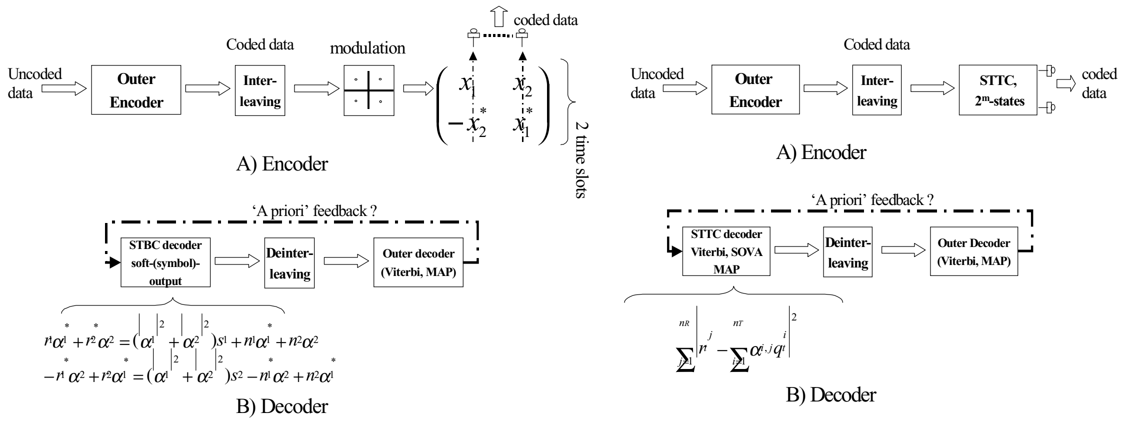

Figure 2: Space-time block (Alamouti) encoder and decoder (left) and space-time trellis encoder and decoder (right).

Although STBC provide transmit diversity gain, they do not supply relevant coding gain and using an outer channel code is mandatory. Figure 2 (left) shows the concatenation of a STBC (Alamouti) and a convolutional code separated with an interleaver. The metrics to generate soft-output values out from the STBC decoder are also detailed. After deinterleaving these metrics feed the outer decoder algorithm. Feedback information is considered to be supplied to the inner decoder (STBC decoder) from the outer channel decoder in an iterative fashion. Nevertheless in most cases the STBC will provide diversity advantage and the outer channel code will produce coding gain. From this point of view any iteration process will be useless.

3.2 Space-Time Trellis Codes

STTC [4] are defined over a trellis structure where each input symbol has associated n_T symbols, each one of them transmitted from each antenna. We note again that no bandwidth expansion is required for this code. Maximum-likelihood sequence estimation MLSE should be performed to decode these codes, which increases the computational complexity that was required for decoding STBC. However STTC, in addition to the diversity gain, also offer some coding gain, hence iterative decoding algorithms seem quite reasonable, as depicted in Figure 2 (right).

3.3 BLAST

BLAST is a new bandwidth-efficient transmitter architecture, which takes advantage of the spatial dimension by transmitting and detecting a number of independent co-channel data streams (substreams) each one transmitted from a different antenna [[5]-[7]]. However, BLAST does not encode the signal to generate orthogonality between antennas, hence there is no 'space encoding'. A general system without 'space encoding' is depicted in Figure 3.
Basically, the bitstream (coded or uncoded data from previous blocks) is demultiplexed into different substreams (one per each transmit antenna), encoded into symbols and fed to its respective transmit antenna.

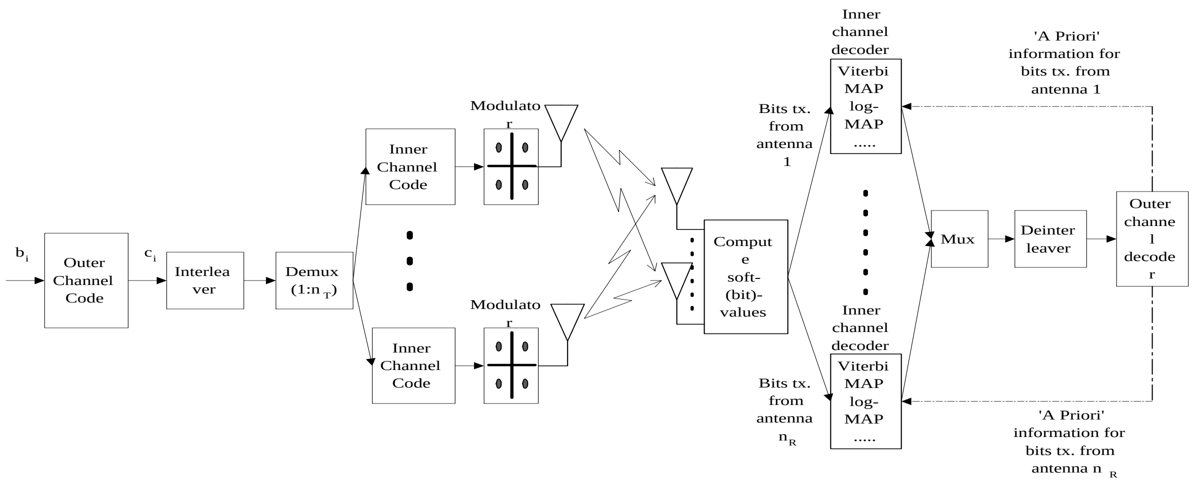

Figure 3: Block diagram of a transmitter and reciever using more than one transmit and receive antenna without space encoding.

Depending on how is the encoding of these substreams defined this architecture leads to Vertical-BLAST (V-BLAST) or Diagonal-BLAST (D-BLAST). The first encodes each substream independently from the others by a channel code (i.e. convolutional code) without introducing any inter-substream redundancy, hence each antenna transmits different bits encoded independently from the others, in contrast to STBC or STTC where all bits are transmitted “directly or indirectly” from all antennas. On the other hand D-BLAST introduces redundancy between all substreams through

specific coding strategy. This approach offers higher spectral efficiencies than V-BLAST, although it also requires higher computational complexity.
As described in [5] the detection process for layered space-time coding of all substreams is divided into three key aspects: interference nulling, interference cancelling and compensation. Interference nulling projects out interference from those substreams not yet detected, interference cancelling substracts out interference of those substreams already detected, finally stronger substreams compensates weaker ones. Alternatively, we can compute the log-likelihood ratios of the transmitted bits directly for the received signals $r_j(t)$. For the V-BLAST architecture a multiuser detector can also be considered since data transmitted from each antenna is independent from data transmitted from other antennas.
Two different scenarios are considered:
TD.1) Outer code: turbo code rate 1/3. Inner code: 8-state convolutional code rate 1/2.
TD.2) Outer code: turbo code rate 1/6. Non inner code.

4 Simulation Results

Simulations have been carried out to analyse the performance of the aforementioned transmit diversity systems in terms of Bit Error Rate (BER) and Block Error Rate. A block error occurs if at least one bit of the burst is in error.

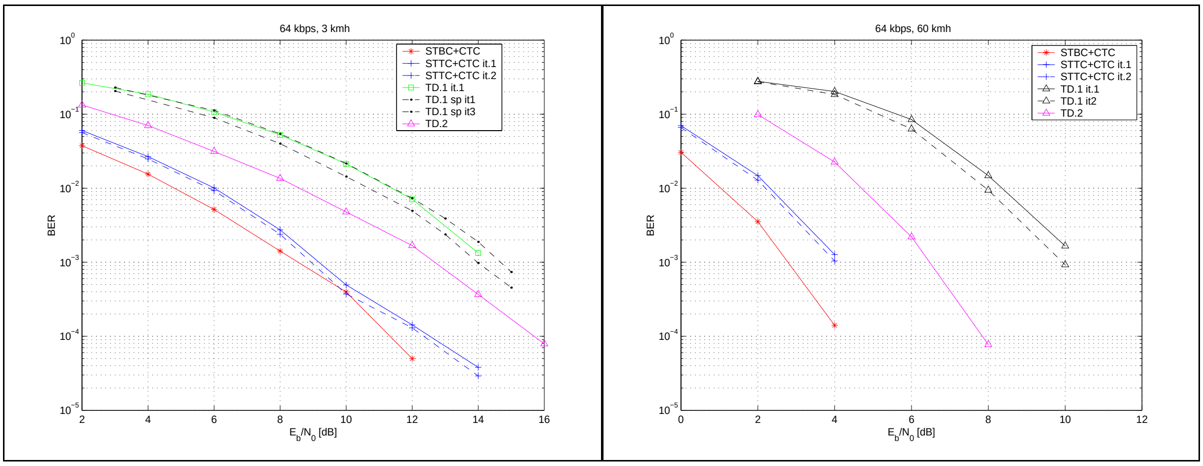

Figure 4: BER for 64 Kbps service at 3 kmh and 60 kmh

Figure 4 show the results for a 64 kbps service at 3 and 60 km/h, repspectively. We note that TD.2 scheme improves with more than 2 dB the BER achieved by scheme TD.1. This suggests that is better to perform inter-substream coding, i.e. generate code redundancy through different substreams, rather than independently encode each antenna branch. At 3 km/h there is no improvement by performing more than 2 turbo-decoding iterations. Since the channel remains almost constant during the whole transmission there is no time diversity to be exploited by the interleaver between component codes. At 60kmh the turbo decoder still improves the BER after 2 iterations. Simulations presented have been run with 4 turbo decoder iterations. We must note that we are assuming perfect channel estimation, whereas imperfect channel estimation based on the training sequence will decrease the performance. We also observe that no significant iteration gain is achieved by feeding back soft information from the inner to the outer code when using STBC or 4-states STTC neither at 3 km/h nor at 60kmh. Using scheme TD.1 it is possible to obtain an additional (small) iteration gain at 3 km/h, but at the expense of high decoding complexity, because feedback information for all (coded and uncoded) bits should be computed. Nevertheless, at 3 km/h, this iteration gain is only about 0.5 dB at the same E_b/N_0. At 60 km/h, TD.1 also offers small iteration gain, but in this case only feedback information for uncoded bits was computed.
In Figure 5 we present performance results for a 384 kbps service at 3 km/h and 60 km/h, respectively. The packet length to the encoder is 7680 bits, which is divided in two packets of length 3840 because it exceeds the maximum encode size.

Transmit diversity scheme TD.2 outperforms scheme TD.1. In these simulations only feedback information for uncoded bits was computed and no significant iteration gain was observed.

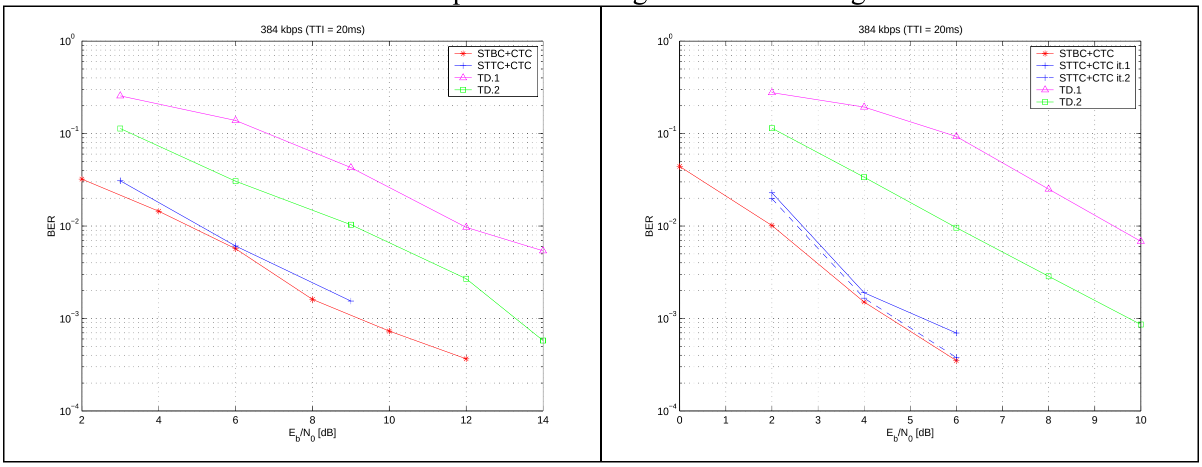

Figure 5: BER for 384 Kbps service at 3 kmh and 60 kmh

5 Conclusions

In this paper, we presented the performance of different transmit diversity techniques combining space-time codes with an outer channel code using two transmit antennas. We observed that STBC outperform all other concatenation schemes considered in this paper.

However, there are many other alternatives to be studied. Different structures for TD than those presented in this paper based on, for example, multilevel coding could also be considered. Extensions to more than 2 transmit antennas should also be studied. STBC and STTC can easily be extended to higher number of transmit antennas, although STBC with more than two antennas have a rate lower than 1. Future work dealing with the aforementioned alternatives will be carried out as part of the METRA project. Updated information about the METRA project including public deliverables can be found at http://www.ist-metra.org/.

6 References

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